

Experimental Standard-Frequency

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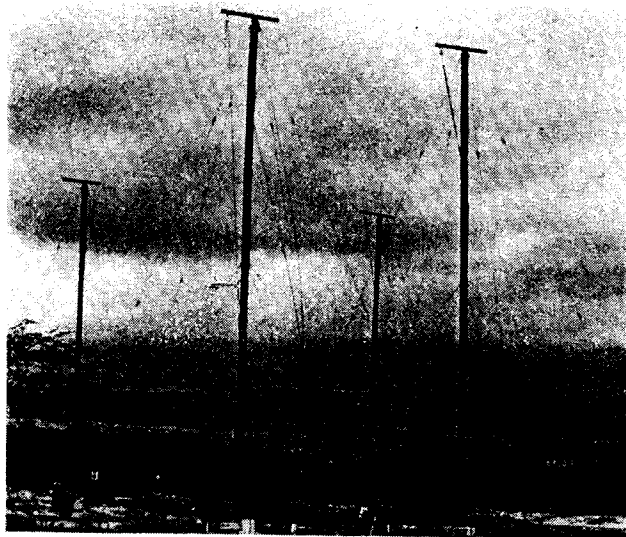


Figure 1

Antennas at WWVH. Left-hand pole in foreground supports a 10-mc, center-fed half-wave antenna. The right-hand pole supports a reflector if directivity is desired. In the background are similar poles for the 5-mc transmitter. This antenna is quarter wave, end-fed from the tuning house shown at the base of the pole.

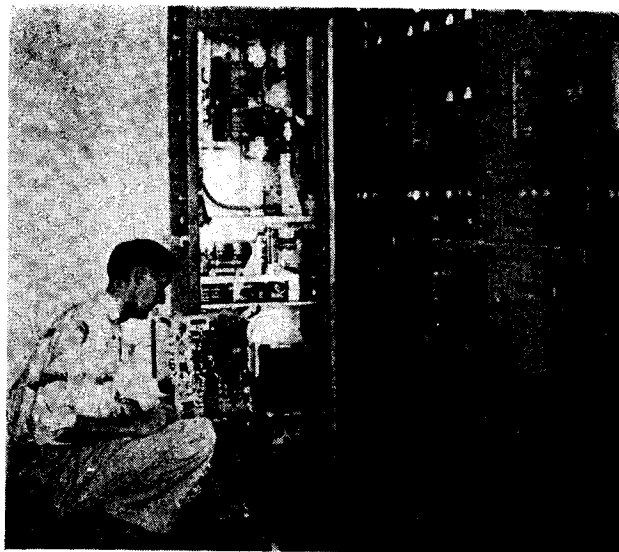


Figure 2

WWVH transmitters. Three transmitters are mounted in line; two are shown. Units are easily rolled out for servicing. Overhead are 600-ohm balanced *rf* transmission lines.

RESULTS OF THE International Telecommunications Conference, held at Atlantic City in the summer of 1947, included agreements that all standard-frequency broadcasts be confined to narrow channels centered on 2.5, 5, 10, 15, 20, and 25 mc. For a number of years all of these frequencies have been used by WWV of the National Bureau of Standards to transmit standard frequencies and time signals on a continuous 24-hour basis.

In November, 1948, the Central Radio Propagation Laboratory began operation of a remotely located experimental standard-frequency transmitting station, WWVH, to obtain data for studying methods of effectively providing continuous world coverage of standard-frequency and time-signal services. Data on reception from this station are being collected for use in determining:

- Order of accuracy attainable in synchronizing two or more standard-frequency stations.
- Increase in the effective service area provided.
- Method of operating separate stations on the same frequency; i.e., simultaneous broadcasts or time division among different stations.
- Best locations for the different stations.
- Interference to present users of WWV services.

Transmitting Site

The CRPL field station at Kihei,¹

Island of Maui, Territory of Hawaii, where an ionosphere sounding station already was in operation, was selected as being a suitable distance from Washington and having sufficient building space and land area to accommodate the experimental equipment.

The frequencies assigned to WWVH were 5, 10, and 15 mc. Of the group of frequencies mentioned, these three were found satisfactory for investigating day- and night-time transmission conditions on a long-time basis.

Antennas

The antenna installation presented the greatest problem and had to be a compromise between expediency in getting the station into operation or waiting until poles of the desired height could be obtained from the mainland. The station was located on a small point of land extending into Maalaea Bay on the south shore of Maui. The main building was located less than 50 feet from the water at high tide and the area available for the antenna installation was a low sand flat, on two sides of the building,

¹The coordinates of the site are north 20°46'02" and west 156°27'42". The site, about 4 acres in extent, has a maximum elevation of about 10 feet. Portions of the area are occasionally flooded during heavy rains or when the monthly high tides are accompanied by high winds. The prevailing trade winds, deflected somewhat by a nearby mountain range, are from the northeast and have a daily average maximum velocity of 25 to 30 miles per hour. The mean average daily temperature is 74°F.

that is occasionally inundated because of heavy rains in the winter season, or when high winds prevail at semi-monthly periods.

The antennas selected were vertical radiators with provision for reflectors that could be erected in approximately 5 minutes should directional transmission be desired. The 5-mc antenna was quarter-wave and 10-mc, a half-wave dipole antenna were supported on guyed 50-foot hexagonal sectional plywood masts. These masts were erected on concrete pedestals extending above the ground to give a firm base and also to obtain sufficient added height providing insurance that the antenna base insulators would be above the water level when the area was flooded.

The half-wave 15-mc dipole antenna was supported on a 45-foot impregnated wood pole, with a braced cross-arm arrangement at the top providing support of both the antenna and reflector by the same pole.

It was decided to feed the antennas by 600-ohm open-wire transmission lines constructed of No. 8 *avg* hard-drawn copper wire spaced 9 inches. The open-wire type of transmission line was used because it has low loss, is easy to adjust with few instruments, is readily inspected and repaired, and is relatively reliable over long periods of time. On the 10- and 15-mc transmission lines, stub matching was used to minimize the standing waves. A small wooden enclosure at the base of the 5-mc antenna housed an *rf* trans-

former to antenna.

The frequency was measured on completion of the antenna. The 10 mc, 1.0 were also on the station used. In wave ratio was not correct readjusting formers were desired.

Transmitters

The transmission was made applicable for various conditions. The transmitters were stocked in operation. The units were included would be and rear for out type provided, for routine.

The required plate supplying voltages for four channels. rectifier no single mode ply a seco

The high use 872-A and most interchange output of in the 2 to included stage, a immediate a cooled WI stage. Provided for sired. The cuits to r frequency tion of th and 15 m modulated audio power of deliver carrier plus load of 60 adjusted the output below the

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Transmitting Station, WWVH

former to end-feed the quarter-wave antenna.

The following *vsur*'s were measured on the transmission lines at the completion of adjustments: 5 mc, 1.18; 10 mc, 1.02; and 15 mc, 1.08. Tests were also made to determine the effect on the *sur* when the reflectors were used. In no case did the standing-wave ratio exceed 1.5. This change was not considered sufficient to justify readjusting the line-matching transformers if directional transmissions were desired for certain tests.

Transmitters

The transmitters used in this installation were commercial units applicable for operation in remote locations. They were designed to minimize the number of types of tubes and circuit components that must be stocked in order to insure consistent operation. A stationary rectifier unit was included and installed so that it would be accessible from the front and rear for service operations. Roll-out type *rf* and modulator units were provided, also accessible from one side for routine maintenance operations.

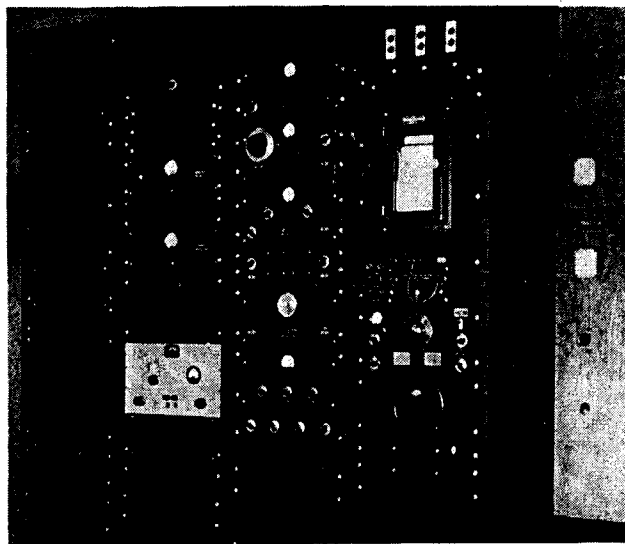
The rectifier unit with its associated plate transformer is capable of supplying bias, low and high plate voltages for as many as four units, i.e., four *cw* channels or two modulated channels. As used at WWVH one rectifier normally supplies power to a single modulated channel but may supply a second channel in emergency.

The high and low-voltage rectifiers use 872-As in conventional circuits, and most of the component parts are interchangeable. The *rf* unit has an output of 3 kw at any one frequency in the 2 to 20-mc band. An 807 was included in a frequency-doubling stage, a 5D24/4-250A as an intermediate amplifier and a forced air-cooled WL473/5736 in the final output stage. Power and space were provided for an internal crystal if desired. This space was used for circuits to multiply a 2.5-mc standard frequency to 5 and 7.5 mc for excitation of the transmitters used on 10 and 15 mc. The transmitters, when modulated 100 per cent with sine-wave audio power, were found to be capable of delivering 3 kw continuously of carrier plus sidebands into a balanced load of 600 ohms. When properly adjusted the total harmonic content in the output was found to be 45 to 50 db below the fundamental.

The modulator unit, with push-pull

Figure 3

WWVH frequency-time standards and monitoring apparatus. Left to right, the 4 racks include: (1) 100-kc frequency standard 1; (2) frequency standard 2 and *rf* multipliers; (3) frequency dividers, clock and time interval generators; (4) control and monitoring equipment.



System, Located at Maui, T. H., Operating on 5, 10 and 15 Mc, Designed to Provide Answers to Variety of Standard-Frequency Time-Signal Service Problems Involved in Operation of More Than One Station on the Frequencies Internationally Assigned for Such Services.

by G. H. LESTER

Central Radio Propagation Laboratory
National Bureau of Standards

amplification throughout, was provided with peak limiter and automatic gain control circuits that could be easily switched in or out of the circuit as required. Audio input at 600 ohms impedance was transformer-coupled to a pair of 6SK7s which in turn were transformer-coupled to a pair of 807s in the intermediate amplifier. This stage was capacitively-coupled to another pair of 807s as cathode-follower driver tubes for the final 833-A modulator tubes. The modulator unit is capable of delivering 1.8 kw of sustained sine-wave audio power.

Station Equipment

In equipping a standard-frequency transmitting station important considerations are accuracy², reliability,

²Detailed discussion of the accuracy of frequency and time signals is not within the scope of this paper.

and freedom from spurious emissions. In planning a transmitting station, the efficiency and operating costs of the transmitters must be considered. Radio transmitters are not yet available which operate unattended at high efficiency for long periods of time without maintenance. Sealed units having such characteristics would be most desirable and may eventually be obtainable. Power for the station should be reliable and constant in voltage. Continuous power requires duplicate or triplicate sources either from local generators or from separate utilities connected by different routes to the transmitting station or a combination of these methods. The equipment should be protected by suitable finishes, air filtering and drying if deterioration by fungus, blowing sand or salt spray is probable.

The most important part of a standard-frequency station is a fre-

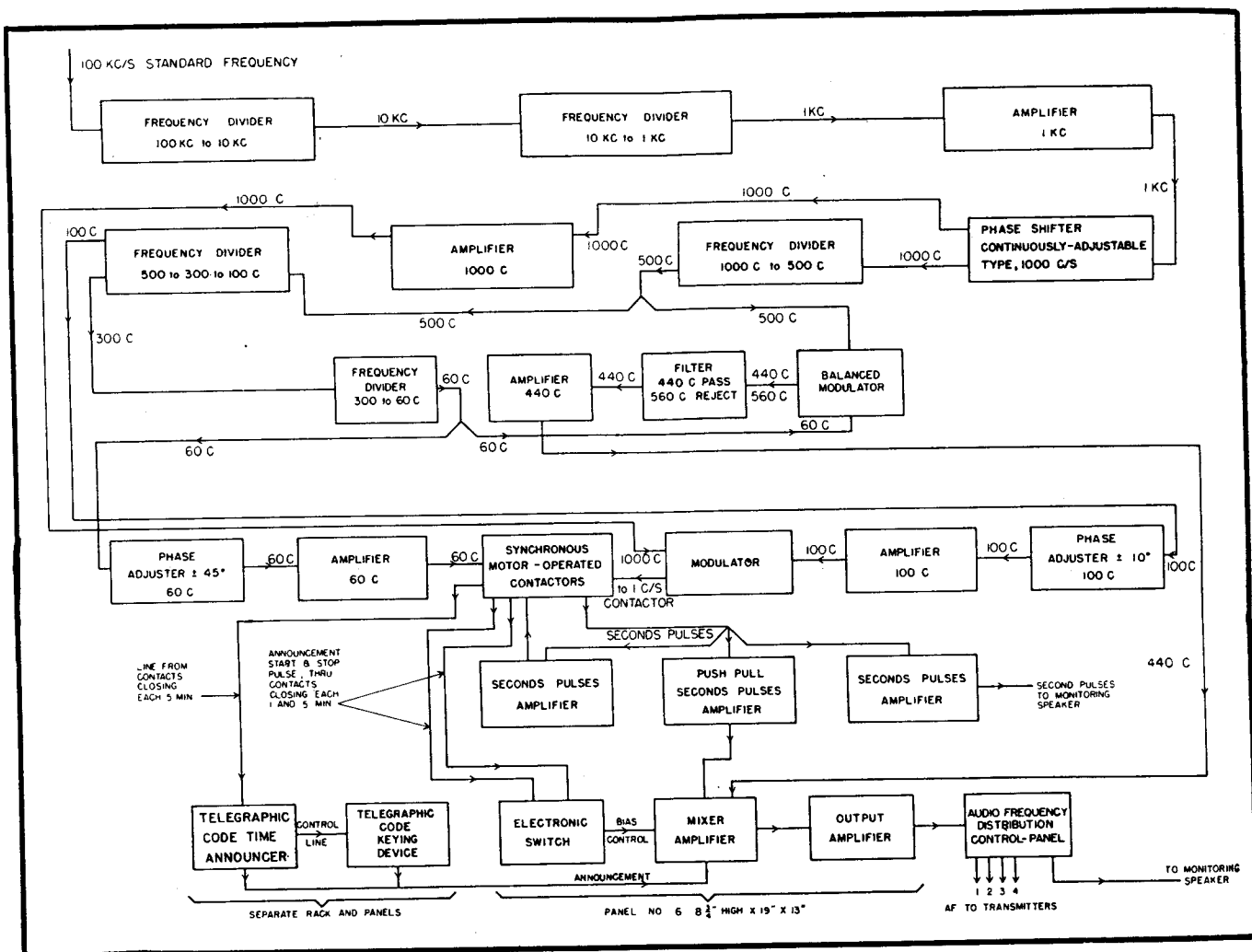


Figure 4

Block schematic of equipment used for composition of standard audio frequencies and time intervals and automatic control of time and telegraphic code announcements.

quency-time standard of great accuracy and stability to control the transmissions. Quartz-crystal controlled oscillators are the best yet available for this purpose. These oscillators should be provided in triplicate to insure accuracy of the broadcasts and to enable local comparison between the different oscillators to determine more easily which particular oscillator varied in drift rate and by how much. To insure the continuity of the broadcasts, provision must be made for duplicate installations of radio- and audio-frequency control equipment. These separate sets must be periodically adjusted to maintain very close agreement with each other. Upon failure of any unit in the chain from piezo oscillator to control output, the alternate set can be used to control the broadcasts.

Certain portions of the submultiple equipment as well as the piezo oscillators must be kept operating during periods of power failure. For this

purpose a set of plate and filament storage batteries and the necessary float chargers must be provided for each control channel.

To facilitate the installation of WWVH, a complete set of frequency and time control equipment from WWV was revised and reinstalled in Hawaii. Revision consisted of providing rack-mounted piezo oscillators and relocation of some units.

The frequency-time standard and monitoring racks now used at WWVH contain one rack with a 100-kc frequency standard with its associated amplifier to furnish two isolated 100-kc outputs. One of these outputs is used to furnish excitation for the *rf* multiplier equipment and the other to control the *af* derivation equipment for the production of time signals and modulation frequencies.

Another rack contains (a) telegraphic code time announcer for giving the correct time every five minutes in GMT, by means of telegraphic

code, starting on the 35th second of every announcement interval; (b) keying device for identification of the station (unit keys the call letters WWVH twice in telegraphic code 5 seconds after the completion of the time announcement); (c) frequency multiplier consisting of a single-stage 100-kc amplifier and two push-pull quintupler stages; (d) *rf* distribution amplifier using four 807s with the grids driven in parallel but with individual isolated plate output circuits delivering two watts at 2500 kc to 70-ohm coaxial lines for transmitter excitation; and (e) 100-kc piezo oscillator, its associated amplifier, a power supply voltage filter and voltage regulator unit.

As 2.5 mc is the lowest standard frequency that may be transmitted, it is economical to multiply the control frequency to this value in one unit, thus materially reducing the number of multiplier stages required in the individual transmitters. The 100-2500

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kc multiplier output is approximately one watt into a 70-ohm line. Unwanted harmonics are down 50 db and modulation products are attenuated by more than 70 db. Type 807 tubes operated very conservatively were used in the balanced quintupler stages to insure reliability.

A third rack contains the following equipment, starting at the top:

(a) A second telegraphic code time announcer unit, which operates in conjunction with the one on top of the adjacent rack, and acts as a check unit to remove all time signals from the air if either of the two units falls out of step with the other.

(b) Frequency divider unit.

(c) Phase shifter and frequency divider.

(d) Divider - multiplier - modulator unit.

(e) Monitoring panel for aurally checking the audio signals used to modulate the transmitters.

(f) Seconds pulse generator and time interval selector unit.

(g) Mixer amplifier unit.

(h) Individual gain controls for remotely adjusting the modulation level of the transmitters.

(i) Regulated power supply for mixer amplifier unit.

All but the top unit on this rack are used in derivation of the standard audio frequencies, standard-time and time-interval signals occurring at intervals of 1, 4, 5, 9, 10, etc., minutes.

The dividers employ tubes operating as class A amplifiers with voltages from tuned circuits in the plate reflexed and mixed with the input frequency in a balanced modulator circuit. The modulator type of divider has a distinct advantage in that it does not self-oscillate but requires an externally supplied input voltage of the proper frequency before any output voltage can be obtained.

The second unit on this rack contains two 10-to-1 frequency dividers which furnish a 1-kc output from a 100-kc input from the frequency standard. A 1-kc amplifier is also incorporated in this unit.

The large dial at the left of the third unit is on the rotor shaft of a selsyn unit operating at 1000 cycles. By manually turning the rotor, cycles can be added to or subtracted from the input frequency. This phase shifter permits the time signals generated in a later unit to be advanced or retarded and set in exact agreement with any time signal. With the unit it is possible to set the seconds pulses from two similar divider chains in agreement within ± 2 microseconds using an ordinary 'scope. The frequency divider operating from the

output of the phase shifter furnishes output voltages at 500, 300, and 100 cycles.

The frequency divider in the fourth unit, excited by 300 cps has an output at 60 cps. In a balanced modulator supplied with 60 and 500 cps the output is 440 and 560 cps. This output is passed through a filter network which rejects the 560 cps signal and passes 440 cps, the standard of musical pitch corresponding to A above middle C.

The 1000-cycle signal is used to excite a frequency multiplier which has an output frequency of 4000 cycles. A mixer unit is provided for furnishing a tone consisting of equal amplitudes of 440 and 4000 cycles for modulating the transmitters.

The 100- and 1000-cycle signals from previous units are mixed in a balanced modulator circuit and a series of pulses, each consisting of 5 cycles of 1000 cycles, is generated. To produce good sine-wave pulses, a phase shifter is provided in the 100-cycle circuit to adjust the phase so that both voltages are at zero simultaneously.

The 60 cycles from the previous unit is converted into 2-phase 60 cycles which is amplified to drive a self-starting synchronous motor having an output shaft speed of 1-rps. A set of contacts operated by a cam on the 1-rps shaft is closed each revolution for a period of about 10 milliseconds. This mechanical gate allows one pulse per second from the 100 pulses per second to pass into an external circuit.

By reduction gears the clock motor also drives cam shafts which have speeds of 1 rpm and 12 rph. Exactly on the proper minute of the five-minute interval in the hour and on the proper second of the minute these cams close switches and channel a seconds pulse into one branch of an electronic switch. This switch operates, and in so doing puts cut-off bias on the tone branch of the mixer amplifier unit and establishes normal operating bias on the announcement branch. Whatever intelligence is desired is passed through the announcement branch to modulate the transmitters.

Exactly one minute later on the hour and each five-minute interval thereafter another seconds pulse is channeled into the electronic switch where it operates to put cut-off bias on the announcements branch of the mixer and to establish normal operating bias on the tone branch.

From the foregoing it can be seen that the mechanical contacts function only as gates to channel the seconds pulses into the proper circuits. The

seconds pulse derived from the 100-kc standard is the determining element in the accuracy of the time intervals.

Monitoring Equipment

In rack 4 of the WWVH set up are the remote control equipment and monitoring recorder, as well as the equipment for monitoring WWV, to maintain the accuracy of the frequency and time signals of WWVH.

The top panel on this rack contains the relays for synchronizing the operation of the WWVH and the ionosphere sounding transmitters.

On the second panel is a manually operated remote control unit for the WWVH transmitters. Push-button type switches shut off the transmitters completely. Rotary type switches permit the removal of the plate voltages of the *rf* modulator or rectifier units as desired.

A time recorder for monitoring the automatic features of the installation is mounted on the third panel.

Other equipment on this rack is used for maintaining the WWVH oscillators in agreement with the the WWV transmissions.

The ionosphere sounding transmitter operates on the hour and half-hour and in one-minute sweeps through the range 2.2 to 16 mc. Supplementary manual observations are required when the vertical-incidence critical frequency exceeds 16 mc. Some means had to be provided for synchronizing the two sets of equipment as the high fields from WWVH signals caused unsatisfactory records from the sensitive automatic ionosphere equipment. This was accomplished by means of two cam-operated switches on the clock unit operated from the frequency standard. One switch is closed for a very short period of time to send a starting pulse to the sounding transmitter. The transmitter automatically shuts off after completing the sweep. Coincident with the above, a long-period cam operates a switch to shut down the WWVH transmitters. These transmitters remain off for 4 minutes and 20 seconds to permit manual ionosphere observations if required. The interval of 4 minutes and 20 seconds is the maximum amount of time that will permit WWVH transmitters to mark accurately the hour and 30-minute intervals before shutting down and still permit them to return to the air in time to give the telegraphic code announcement for the 5- and 35-minute intervals.

The recorder in the third panel of the rack is equipped with 20 relay-op-

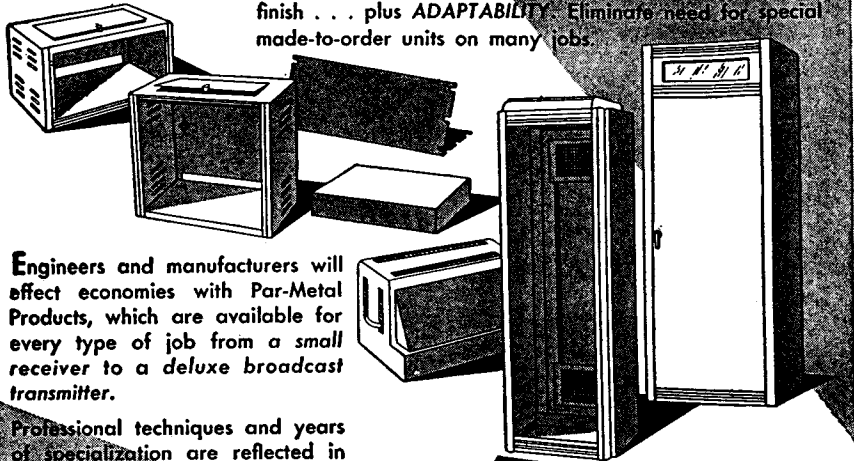
(Continued on page 32)



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The WWVH Station

(Continued from page 23)

erated pens. Each relay coil circuit is isolated and will operate from either 110 volts *ac* or low-voltage *dc*. There are three pen circuits per transmitter, one each for the rectifier, modulator, and *rf* unit. Their purpose is to record the time and number of momentary overloads or a complete failure of the unit. Where equipment is operating unattended several hours every day a record of this type facilitates the location of faults causing transmitter outage, or in the case of recurring overloads in a particular unit, indicates impending failures. Additional pens are connected across modulation control circuits to indicate that the tone is removed for one minute every five minutes and also that the time-announcement and station-identification keying units are functioning correctly. Pens are also connected to the heater circuits in the 100-kc frequency standards to indicate proper operation and any changes in the heater cycle caused by changes in ambient temperature.

Agreement with WWV transmissions is determined either by direct frequency comparison or by obtaining an average frequency for a period de-

rived from the time kept by the synchronously-driven local clocks compared with the time signals transmitted by WWV.

The ideal monitoring system would require a separate receiving site located to the east of the WWVH transmitting station. Highly directive receiving antennas would provide sufficient discrimination to permit simultaneous reception of both stations. Continuously operating recorders on each of the transmitted frequencies would provide a permanent record of the frequency and time differences between the two transmitted signals.

In the present installation the monitoring is done at the transmitting site which requires that the WWVH transmitter be shut down for a period twice daily, at 0700 and 1900 GMT, to permit reception of WWV. The harmonic relationship of the frequencies to be received from WWV made it possible to erect a simplified wide-band antenna which had a major lobe oriented on Washington, D. C.

Located below the time recorder is a harmonic generator unit and the associated *hf* radio receiver used in mak-

ing direct comparisons in frequency between the local standard oscillators or one local oscillator and the WWV received frequency. The harmonic generator consists of two identical units, each provided with a gain control to adjust the injection level into the receiver. To compare the local oscillators the receiver is tuned to the desired harmonic and the input connected to the harmonic-generator output terminals. Each harmonic generator is controlled by a separate frequency standard and the levels are adjusted for equal amplitude by means of an S-meter in the radio receiver. The aural beat note may be counted by observing the swing of the S-meter pointer as the phase relationship of the two frequencies changes. A number of independent checks are made on the time required for a fixed number of beats. These values are averaged and this averaged value is used to obtain the frequency difference. In a unit length of time the accuracy of inter-comparing the standard oscillators increases by a factor equal to the harmonic order at which the measurement is made.

When the frequency of one of the local standard oscillators is to be checked against WWV, the receiver obtains its input from the antenna and one of the harmonic generators. The receiver is tuned to an assigned frequency, for which transmission conditions are optimum, to minimize the effects of fading. The measurement procedure is the same as previously outlined.

Frequency determinations made by checking the time kept by the local clocks are accomplished by comparing the local and received seconds pulses on a 'scope. The linear sweep is controlled at 60 cycles from an external source obtained from the standard-frequency generators. While alternately observing the position of the local and received seconds pulses the phase shifter is adjusted until coincidence is obtained with the earliest pulse received from WWV. Vagaries of the transmitting medium may cause two successive received pulses to vary as much as 3 or 4 milliseconds in the time of arrival. By using the earliest pulse received, adjustment is made to the pulse arriving by the shortest possible path and hence with the minimum delay in transmission.

After obtaining coincidence the phase-shifter dial is read to the nearest tenth of a millisecond. This reading compared with similar readings taken 48 and 96 hours previously, gives the number of milliseconds that the synchronously-driven local clock has gained or lost during the period.

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tion of time interval, to determine the oscillator frequency, the number of oscillations in a definite interval of time must be known. Assuming that the rate of drift of the oscillator has been uniform throughout the period under consideration, the average frequency for the period is the same as the instantaneous frequency for the middle of the period. The latter method is the one normally used in maintaining the WWVH frequencies in agreement with WWV.

After obtaining agreement between the local and received pulses the phase shifter is advanced 27 milliseconds before transmissions are resumed. This 27-milliseconds is the average transit-time for the Washington-to-Maui path.

Frequency Conversion

(Continued from page 19)

on hand the voltage regulation of the 81-cycle current was rather poor, resulting in sluggish starting of the motor. Therefore, we found it necessary to start the motor with 60-cycle power and then switch to 81 cycles. Our disc jockeys have had no difficulty in operating the system in this manner, simply holding the record until 45 rpm is reached, about one revolution after switchover.

To accommodate the 45-rpm records, the large center hole in the records was provided by a drilled bakelite disc.² Our pickup arm,³ with a filter transformer⁴ with output impedances of 250, 150, and 37.5 ohms, was mounted 14" to the left of the regular pickup arm so that it would not interfere with the playing of regular records and transcriptions.

²Available from Webster. ³Astatic FLT-33. ⁴Astatic FT.

Video Scanner

(Continued from page 25)

other unit of a system. The switch, located on the picture generator chassis, can be paralleled by a remotely located switch.

Picture output amplitude can be adjusted by varying the voltage applied to the dynode stages of the phototube.

Color Slides

It was found possible to use color slides in the scanner. The signal-to-

RADAR SYSTEMS AND COMPONENTS

By Members of the Technical Staff of
Bell Telephone Laboratories

This great, new book explains RADAR from basic principles to the details of equipment design. General descriptions of various radar systems are followed by complete accounts of every step in the analysis and design of magnetrons, pulse modulator tubes, receivers, oscillators, rectifiers, antennas, switches, and other components of radar systems.

EVERY one of these topics is explained in detail and is illustrated with many circuit diagrams, line drawings, and specially prepared photographs (including actual X-ray photographs) showing the inner construction and operation of the equipment.

One of many valuable features of this book is its extensive treatment of the development of radar equipment such as the magnetron oscillator of the Bell Telephone Laboratories. This information is especially valuable as a basis for understanding the more recent methods of operation and types of equipment. A remarkable array of charts and tables makes all quantitative data readily available for instant reference.

Exhaustively detailed and clearly illustrated chapters cover the subject of radar completely. Here is a brief outline of the contents of this work:

Early Fire-Control Radars for Naval Vessels; The Magnetron as a Generator of Centimeter Waves; High Vacuum Oxide-Cathode Pulse Modulator Tubes; Coil Pulsers for Radar; Spark-Gap Switches for Radar; The Gas-Discharge Transmit-Receive Switch; The Radar Receiver; Reflex Oscillators; Development of Silicon Crystal Rectifiers for Microwave Radar Receivers; Characteristics of Vacuum Tubes for Radar Intermediate Frequency Amplifiers; Radar Antennas; Techniques and Facilities for Microwave Radar Testing; High Q Test Sets for Microwave Testing; End Plate and Side Wall Currents in Circular Cavity Resonators; and Some Results on Cylindrical Cavity Resonators.

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noise ratio was found to be slightly poorer than when good black and white slides were used because of the greater average density of the color slides.

Credits

Credit is due many members of our labs who participated in the design and construction of the scanner: The research division for the development of the crt; A. J. Baracket who directed initial development of the commercial equipment and A. L. Olson, who was responsible for scanning generator and slide changer designs.

KAY ELECTRIC INSTRUMENTS

Two instruments, the *Mega-Pix* and the *Mega-Node, Sr.*, have been announced by Kay Electric Co., Pine Brook, N. J.

The *Mega-Pix* generates picture and sound carriers in the twelve television channels. Channels are individually selected by a front panel switch. Sound carriers are frequency modulated by an internally generated tone. Frequency deviation is adjustable by front panel control. Picture carrier can be modulated by RMA video signal either from external generator or from a receiver tuned to a transmitter. Modulation depth adjustable by front panel control. Picture modulation double side band. Picture and sound carriers are said to be substantially equal in amplitude and are simultaneously adjustable in level by means of a single panel control.

The *Mega-Node, Sr.*, is a calibrated random noise generator for determining the noise figure (db above ideal) of receivers or amplifiers in the uhf and microwave frequency ranges. The noise figure may be read directly from the panel meter calibrated in linear db.